5.22 EVALUATION OF TURBULENCE FROM TRAFFIC USING EXPERIMENTAL DATA OBTAINED IN A STREET CANYON

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INTRODUCTION

High air pollution levels have been observed in street canyons. Within these streets, pedestrians, cyclists, drivers and residents are likely to be exposed to pollutant concentrations exceeding current air quality standards. Airflow and dispersion in street canyons are very complicated. Depending on the synoptic wind three main dispersion conditions can be identified (*Vardoulakis, S. et al.,* 2003): a) low wind conditions, b) perpendicular or near perpendicular flow for winds over 1.5-2.0 m/s blowing at an angle of more than 30º to the canyon axes, c) parallel or near parallel flow for winds over 1.5-2.0 m/s blowing from all other directions. Under condition b), airflow in canyons with H/W≈1 (H is the height and W is the width of the canyon) is characterised by the formation of a single vortex within the canyon (*Oke, T.,* 1988). The dispersion of gaseous pollutants in a street canyon depends generally on the rate at which the street exchanges air vertically with the above roof-level atmosphere and laterally with connecting streets. There is evidence that when the synoptic wind speed is low, the mechanical traffic-produced turbulence (TPT) might place a significant role in dispersion of traffic-generated pollutants (*Kastner-Klein, P. et al.,* 2003). In this paper, we analyse interactions between wind and traffic induced dispersive air motions. Data from full-scale measurements in Göttinger Strasse (Hannover, Germany) are used for application of parameterisation proposed by *Di Sabatino, S. et al.*(2003) and *Kastner-Klein, P. et al.*(2003).

DATA

Traffic pollution measurements in Göttinger Strasse (Hannover, Germany) have been obtained by a monitoring station located in a street canyon with a traffic volume of approximately 30000 vehicles per day (*NLÖ*, 2000). The canyon aspect ratio (H/W) is 0.8. Automatic traffic counts provide the vehicle flows. Wind direction and speed data are taken at a 10m mast on top of a nearby building. The background concentration sampler is located on the roof of this building.

RESULTS AND DISCUSSION

In our analysis we consider CO hourly concentrations in Göttinger Strasse, registered during 1994. The background CO concentrations (Cb) are subtracted from the values of CO measured inside (Ci) the street canyon (C=Ci-Cb). All cases with a wind direction within ±11.25º from the direction perpendicular to the street axis have been used. The concentration data have been grouped according to a classification based on the hourly total traffic volume. For windward conditions, and considering to have a sufficient number of data point, four classes have been defined: w_1) <600veh/h, w_2) 600-1200veh/h, w_3) 1200-1800veh/h, w_4) >1800veh/h. For leeward conditions, the following seven classes and the estimated traffic velocity were used: l_1) <300veh/h, 50km/h; l_2) 300-600veh/h, 50km/h; l_3) 600-900veh/h, 50km/h; l_4) 900-1200veh/h, 40 km/h; l_5) 1200-1500veh/h, 40 km/h; l_6) 1500-1800veh/h, 40 km/h; l_7) >1800veh/h, 40 km/h.

The values of local concentration (C) were plotted against roof building wind speed (U) for all the classes of total traffic flow, separately for windward and leeward conditions. As an example, in Figure 1 we include the results obtained for windward conditions, for w_1 and w_4 traffic volume groups. It is clearly seen that $C \propto 1/U^m$, with $m \approx 0.55$.

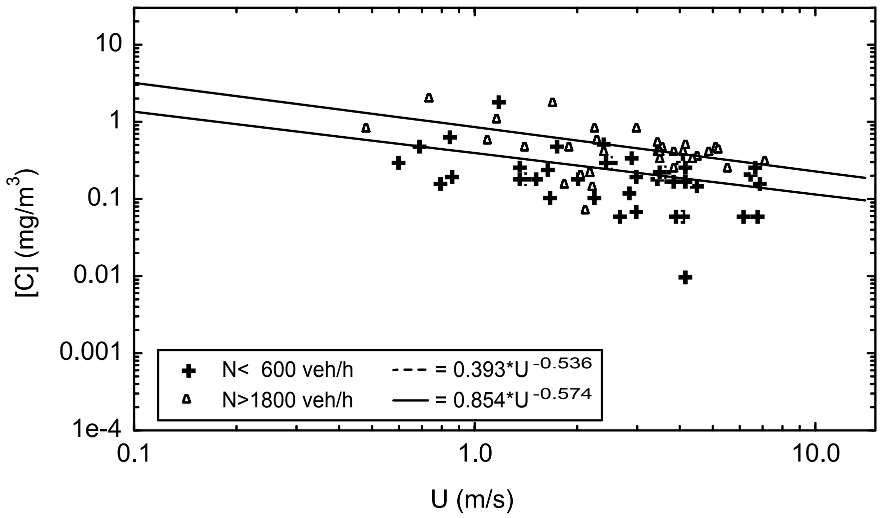

Figure 1. Local CO concentration [C=Ci (inside the street canyon)-Cb(background)] versus wind speed for two traffic flows. Windward conditions.

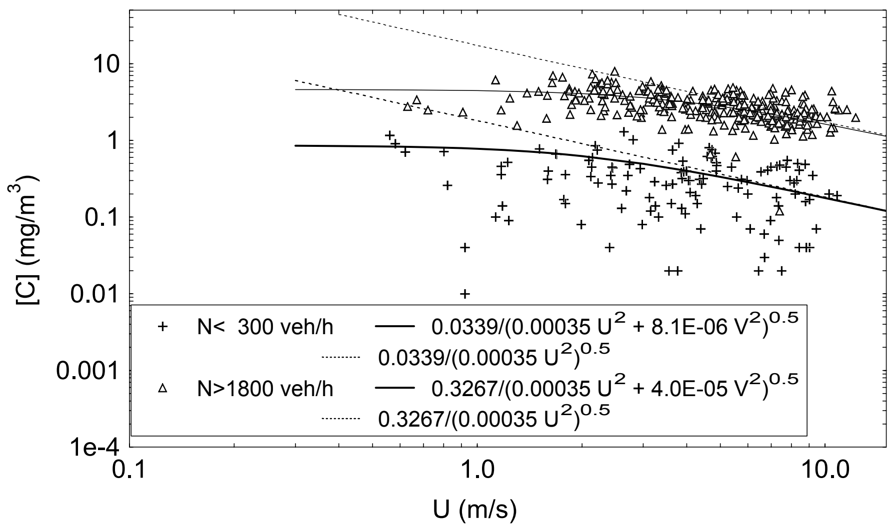

Figure 2. Local CO concentration [C=Ci (inside the street canyon)-Cb(background)] versus wind speed for two traffic flows. Leeward conditions.

Kastner-Klein, P. et al. (2003) propose that the turbulent motions related to wind and traffic are mixed inside the canyon so that the effective velocity variance can be taken proportional to a linear combination of the squares of wind speed (U) and traffic velocity (V). They define the following expression for the dispersive velocity scale (u_S):

$$u_S = \left(aU^2 + bV^2\right)^{1/2} \tag{1}$$

where *a* depends on street geometry, wind direction and sampling position and *b* is a function of vehicles characteristics, their drag coefficient and traffic density (N/V), except congested traffic. Using u_S, street canyon concentration can be expressed by:

$$C \,\alpha\, \frac{1}{u_S} \qquad (2)$$

For large wind velocities, $C \propto 1/a^{1/2}$. We analysed the variation of C with U under leeward conditions, for all traffic classes (l_1 , l_2, …, l_7). As an example, Figure 2 shows C plotted against U for leeward conditions for l_1 and l_7 traffic flow classes. For wind speeds lower than 6 m/s, the fitting curve (solid line) considerable deviates from $C \propto 1/U^m$ (representative of the "without traffic turbulence" condition and indicated with a dashed line). The deflection is more pronounced for classes with higher traffic volume. The wind speed for the transition between the "with" and "without" traffic turbulence regimes depends on the traffic conditions.

Using C data measured during high wind speed we estimated the averaged emission intensity of CO for each traffic class. These estimated emissions and a=0.00035 (proposed by *Kastner-Klein, P. et al,* 2003) were used to obtain the values of b from the fitting curves of C vs. U. The values of b vs. N/V are plotted in Figure 3 along with the fitted curve:

$$b = 6.9x10^{-6} \cdot \exp\left(3.68x10^{-2}\,\mathrm{N/V}\right) \qquad (3)$$

with a regression coefficient of 0.984.

The variation of the ratio [C_o(without vehicle turbulence)-C(with vehicle turbulence)]/C_o with wind speed for different traffic flows (N), is shown in Figure 4. At low wind speeds, C is reduced due to the traffic-induced turbulence. At high wind speeds, the significance of the vehicle turbulence diminishes relative to ambient turbulence levels. If traffic-induced turbulence is equal to wind turbulence, then $(C_o\text{-}C)/C_o \approx 0.29$.

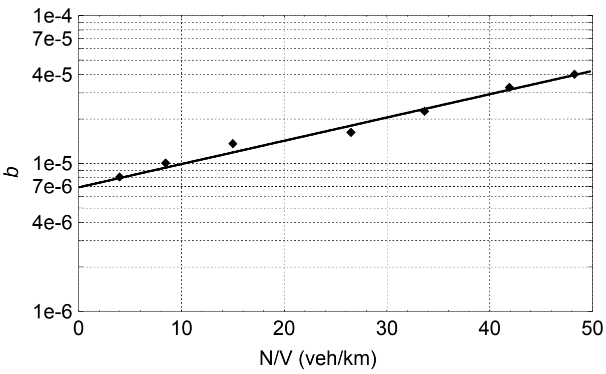

Figure 3. Variation of b (Eq.(1)) with traffic density (N/V). The line shows the best fit [Eq.(3)]

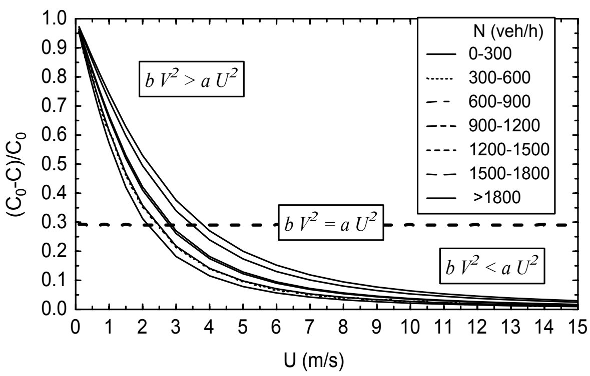

Figure 4. Influence of TPT on concentration with wind speed for different traffic flows.

In Figure 5, the ratio C/C_o is plotted against the ratio (X) between vehicle velocity and the wind speed (V/U) scaled by dimensionless factor $[(N/V)/\beta]^{1/3}$, with β=0.067m^{-1}, for all data on Göttinger Strasse. In this Figure, it is also included the obtained fitted line given by:

$$C/C_o = \frac{1}{1+0.079122\,X^{1.5153}} \qquad (4)$$

and the regression expressions proposed by Kastner-Kein, P. et al. (1998): C/C_o =1-018X and Stern, R. and R. J. Yamartino (2001): C/C_o=1/(1+0.24X). Figure 5 shows that when X < 6.0, the differences between C/C_o given by Eq.(4) and Stern-Yamartino's curve is about 0.1.

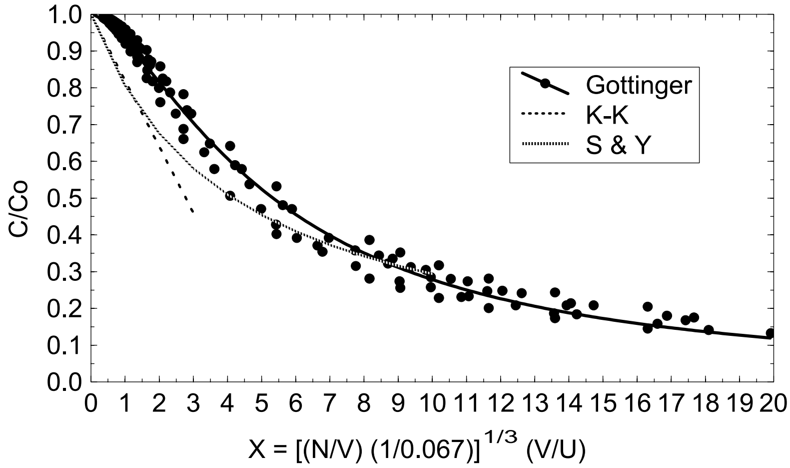

Figure 5. Influence of TPT. Comparison of on site results (Göttinger Strasse) with wind tunnel result (K-K) and model simulation (S&Y). See text for further explanations.

In Figure 6, the ratio $P=aU^2/bV^2$ is plotted against U for different traffic conditions. The plots may be separated in two intervals: for P > 1.0 and for P < 1.0. The wind speed (critical wind speed, U_C) that makes P= 1.0 depends on vehicle flow. For low traffic flow, critical wind speed (U_C) is about 2m/s and for high vehicle volume $U_C \approx$ 4m/s. P=0.1 is reached for 6.5 <U<12.0m/s and P=10 for 0.65<U<1.2 m/s.

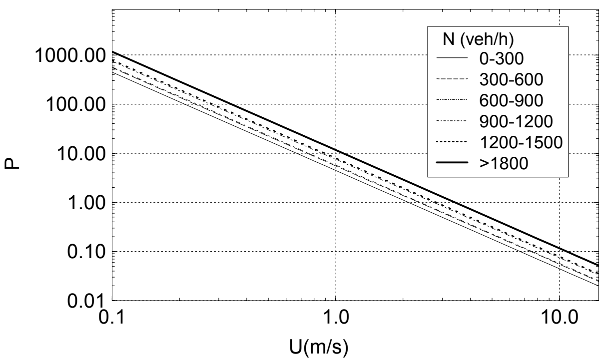

Figure 6. Calculated ratio $P=aU^2/bV^2$, as function of wind speed, for different traffic flows.

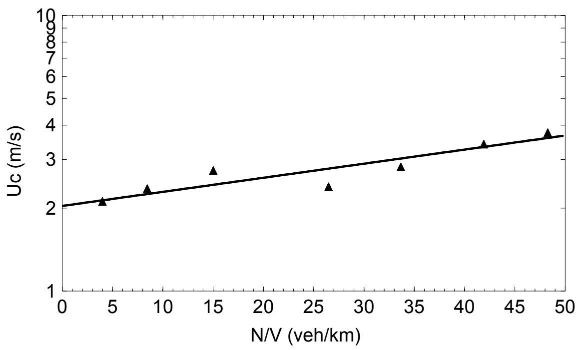

Figure 7. Variation of critical wind speed with traffic density. The line shows the best fit [Eq.(5)]

The values of critical wind speed (U_C) obtained for the different traffic density (N/V) are presented in Figure 7, along with the fitted line obtained:

$$U_c = 2.037 \exp[0.0118 \ N/V] \tag{5}$$

Finally, from Figure 4, it can be found that C/C_o= 0.71 when $U=U_C$, not depending on traffic flow condition.

CONCLUSIONS

Vehicle induced turbulence is an important factor of pollution dispersion in streets. Traffic pollution measurements in Göttinger Strasse (Hannover, Germany) have provided one of the most comprehensive dataset of flow and air quality in a typical urban street canyon. All of cases for 1994 with wind direction within ±11.25º from the direction perpendicular to the street axis were used. Analysis of these data showed that for windward, $C \propto 1/U^m$, with values of m close to 0.55. However, for leeward, considerable deviation from $C \propto 1/U^m$ was observed, especially for wind speed lower than 6 m/s. Concentration is function of the turbulent motions related to wind (proportional to the square of wind speed) and traffic (proportional to the square of traffic velocity). In the last case, the value of the proportionality coefficient (*b*) depends primarily of vehicular density. Turbulent energy originated by wind and vehicular motions are similar when the wind reaches the critical value, U_C. This critical wind speed (2m/s-4m/s) varies with traffic flows. When $U=U_C$, the traffic-produced turbulence dilutes the concentration in the street canyon to 0.71 times the concentration obtained without vehicular turbulence.

ACKNOWLEDGEMENTS

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REFERENCES

Di Sabatino, S, P. Kastner-Klein, R. Berkowicz, R.E. Britter and E. Fedorovich, 2003: The modelling of turbulence form traffic in urban dispersion models - Part I: Theoretical considerations. *Environmental Fluid Mechanics*, 3, 129-143.

Kastner-Klein, P, R. Berkowicz, A. Rastetter and E. J. Plate, 1998: Modeling of vehicle-induced turbulence in air pollution studies for streets. Fifth International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 18-21 May, Rodhes, Greece.

Kastner-Klein, P, E. Fedorovich, M. Ketzel, R. Berkowicz and R. Britter, 2003: The modelling of turbulence from traffic in urban dispersion models - Part II: Evaluation against laboratory and full-scale concentration measurements in street canyons. *Environmental Fluid Mechanics*, 3, 145-172.

N.L.Ö. 2000: Lufthygienische Überwachungssystem Niedersachsen - Niedersächsisches Landesamt für Ökologie, Research Network TRAPOS. Available on http://www.dmu.dk/atmosphericenvironment/Trapos/datadoc.htm

Oke, T, 1988: Street design and urban canopy layer climate. *Energy and Building*, 11, 103-113.

Stern, R. and R.J. Yamartino, 2001: Development and first evaluation of micro-calgrid: a 3-D urban-canopy-scale photochemical model. *Atmospheric Environment*, 35 Supplement 1, S149-S165.

Vardoulakis, S., B.E.A. Fisher, K. Pericleous and N. Gonzalez-Flesca, 2003: Modelling air quality in street canyons: a review. *Atmospheric Environment,* 37, 155-182.